Spectral analysis of sea level in the Gulf of Finland

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Outline:

1. Available data (sea level, NCEP/NCAR reanalysis)

2. Sea level spectrum: discreet and continuum

3. Spatial cross-spectral analysis of sea level: Coherent structures in the Baltic Sea and the Gulf of Finland

4. Helmholtz seiche in Nevskaya Guba

5. Cross-spectral analysis of atmosphere - sea level interaction

6. Discussion
Pressure and wind, 00h UTC, 23 January, 1993
NCEP/NCAR Reanalysis
Tides (amplitude spectra)
Seasonal variation of sea level

St. Petersburg (Gorny Institute)

\[
\langle S(t) \rangle = a_1 \sin(2\pi / T_1 + \phi_1) + a_2 \sin(2\pi / T_2 + \phi_2)
\]

\[a_1 = 19.4 \text{ cm}\]
\[a_2 = 5.8 \text{ cm}\]
\[T_1 = 365.24 \text{ days (SA)}\]
\[T_2 = 182.62 \text{ days (SSA)}\]
Sea level spectrum in Saint Petersburg
Sea level in Kronstadt

Mean 518.2 cm
Standard deviation 31.56 cm

Frequency (cpd)

Period (days)

Spectrum $f S(f)$ (cm$^2$)

1 year

$\frac{1}{2}$ year

2.7 year

D

SD
Cross-spectral functions (station to station)
Frequency response (station to station)
Standing waves in the Gulf of Finland

Coherence

T ≈ 15 hours

Phase (degree)

Frequency (cpd)

Depth ≈ 50 m

310 km
Nevskaya Guba and Saint Petersburg Dam

Kronstadt

Gorny Institute
Helmholtz seiche (organ pipe) mode of Nevskaya Guba

\[ \omega_0 = \sqrt{\frac{gS}{AL_c}}, \text{ where } L_c \text{ is channel length.} \]

If there is no channel length we can introduce an "effective channel length"

\[ L_e \approx B \]

then

\[ \omega_0 \approx \sqrt{\frac{gH}{S}}, \quad T_0 = 2\pi \sqrt{\frac{S}{gH}} \]

\( S \approx 15 \text{ km} \times 30 \text{ km} = 4.5 \cdot 10^8 \text{ m}^2 \)

\( H \approx 3 \text{ m} \) is a mean depth in the mouth

\( B \approx 1500 \text{ m} \) is the width of the mouth

\( T_0 \approx 7 \text{ hours} \)
Nevskaya Guba basin surface area is extended with Neva river delta
Helmholtz seiche in Nevskaya Guba

Period (days)

Frequency response (cm/cm)

Phase (degree)

Helmholtz mode

1-st seiche mode?

T=6 hours

D

SD

Helmholtz mode

1-st seiche mode?
Spectra of atmospheric pressure and wind (S-Petersburg)

Pressure

Wind

Seasonal

Breeze
Atmospheric pressure – Sea level (Saint Petersburg)
Sea level response to wind forcing
Frequency response function
(Saint Petersburg)
The most common free seiche in the Baltic Sea occurs in the system “Western Baltic proper – Gulf of Finland” with period of around 27 hours.

Stochastic wave field in the Gulf of Finland reveals high coherent structure that is typical for standing waves (of random phases) and statistically independent from other parts of the sea.

St.Petersburg Flood Protection Barrier separates Nevskaya Guba from the Gulf of Finland. This area occurred to be a Helmholtz resonator with typical period of 8.5 hours.

Other “isolated” areas that could be statistically independent
Sea level oscillations in the Baltic Sea could be treated as a superposition of standing waves with random amplitudes and phases.

The complicated bathymetry and the form of the coast (gulfs, bays and harbours) create favourable conditions for formation of numerous eigen modes.

Each mode is linked with a specific area of the basin. Gulfs or bays turned out to be a kind of traps for surface waves. Inside such areas the trapped wave field is highly coherent.

If these “trapping areas” are isolated from each other the coherence between the wave fields is low.

If areas are overlapped, the coherence between wave fields is determined by resonant properties of the large (covering) area.
It has sometimes been asked whether the sea level oscillations we observed in the Gulf of Finland are caused by a local gulf mode or by basin-wide eigen modes. These two alternatives are really two sides of the same coin. Mathematically speaking, a local gulf mode is a superposition of several eigen modes with close frequencies. (Bror Jönsson, Kristofer Döös, Jonas Nycander, Peter Lundberg, JGR, 2007)